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Investigation of the Solar Differential Rotation of Compact Magnetic Elements for 1966 – 1986

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Abstract The differential rotation of compact magnetic elements during activity cycles 20 and 21 (1966 – 1986) is studied by using solar synoptic charts. For each hemisphere the compact magnetic elements with the polarity of the circumpolar magnetic field have larger rotation rates than the elements with the opposite polarity. This difference in rotation rates is present during the whole cycle except during the polarity reversal of the circumpolar field.

Keywords Solar differential rotation · Compact magnetic elements · Polarity reversal

1. Introduction

The solar magnetic field is a key to understanding the physical processes in the solar atmosphere. Sunspots, faculae, prominences, and filaments have been used as tracers of the solar rotation (Newton, 1924; Newbegin and Newton, 1931; D'Azambuja and D'Azambuja, 1948; Japaridze and Gigolashvili, 1992; Gigolashvili *et al.*, 1995; Gigolashvili, Japaridze, and Kukhianidze, 2005a). Another class of features used for tracking the large-scale solar pattern motion consists of neutral lines of the magnetic field in filtergrams and spectroheliograms (Durrant, Turner, and Wilson, 2002; Gigolashvili, Japaridze, and Kukhianidze, 2005b; Japaridze, Gigolashvili, and Kukhianidze, 2006, 2007).

DeRosa (2005) found that the surface manifestation of magnetic field within the solar interior exhibits an unexpected degree of regularity, despite such fields being embedded in an extremely turbulent medium. The largest magnetic field observed at the surface follow episodic patterns of emergence and evolution that collectively form the solar activity, although there is evidence that smaller scale magnetic fields also possess an imprint of such

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cyclic behavior. Brun (2004) recently modeled the interaction between differential rotation and magnetic fields in the solar convection zone.

McIntosh, Willock, and Thompson (1991) made Carrington maps of Hα solar synoptic charts and the results were published in the form of an atlas of stackplots. Large-scale stackplots for the entire range of data for 1966 – 1986 include the series of plots displaying 10° zones of solar latitude in the range of ±70°. Segmentation of the charts into stackplots with narrow latitude zones is a valuable method for separating the differential rotation of the Sun. This differential rotation causes long-lived features at the same latitude to move relative to the adjacent latitudes, resulting in complicated interactions of the large-scale patterns.

Snodgrass (1992) found patterns that appear to show features at the same latitude moving at different rotation rates. It is also possible to observe the poleward drift of large-scale unipolar regions and the evolution of the polar cap as well as a variety of other apparent meridional and toroidal motions.

For compact magnetic elements with negative and positive polarities, the average values of statistics were calculated for the solar-activity minimum (1964 – 1966 and 1973 – 1978) and maximum (1967 – 1972 and 1979 – 1983) periods for both northern and southern hemispheres, with 90% confidence levels (Gigolashvili *et al.*, 2007). We study the differential rotation of the compact magnetic elements on McIntosh's stackplots to continue the study of differential rotation of the Sun.

2. Observational Data and Method

To study the differential rotation of compact magnetic elements for cycles 20 and 21 of solar activity (1966 – 1986) we used McIntosh's atlas of synoptic maps (McIntosh, Willock, and Thompson, 1991). From these we have chosen only visually symmetric compact elements with a significant angle of deviation that could be measured for at least three days. This was necessary for determining differential rotation with high accuracy. Rotation rates of large-scale magnetic features change insignificantly with latitude (Snodgrass and Smith, 2001), so our method of selection gives a useful sampling of compact magnetic elements and we can determine their differential rotation.

We measured the angle between the symmetry axis of a chosen magnetic element and the horizontal line parallel to the horizontal edge chosen among five identical plots. The average slope of long-lasting patterns generally varies in a regular way as a function of latitude. Since the frame of reference is the Carrington system of solar longitudes, a vertical pattern in a stackplot represents a pattern rotating at the Carrington synodic rate of 27.2753 days. Patterns with positive or negative slopes indicate rotation rates that are, respectively, faster or slower than the Carrington rate. Rotation rates faster than the Carrington rate usually occur at latitudes less than 20° (McIntosh, Willock, and Thompson, 1991). We calculated the rotation rates for compact magnetic elements using the empirical formula $\Omega(\varphi) = 1000/[36.664 - \cot(\alpha)]$, where α is the angle of the slope, φ is latitude, and $\Omega(\varphi)$ is the rotation rate in $\mathrm{deg\,day}^{-1}$ (Japaridze, Gigolashvili, and Kukhianidze, 2006).

A total of 1675 measurements have been made for 335 chosen compact magnetic elements. Of these, 990 measurements for 198 features and 685 measurements for 137 features have been carried out for cycles 20 and 21, respectively.

3. Analysis of the Data

McIntosh's synoptic maps contain dark and light features with negative and positive polarities, respectively. The dark/light compact elements that we chose are surrounded by more extensive areas of the opposite polarity, representing large-scale formations.

As the patterns in McIntosh's stackplots are displayed both in longitude and latitude, we can trace a number of details. The calculated rotation rates of magnetic elements with positive and negative polarities for low (10°) and middle (60°) latitudinal zones, for both hemispheres of the Sun separately, are presented in Figures 1 – 12. The diagrams for compact magnetic elements with positive and negative polarities for every 10° zone were constructed for the northern and southern hemispheres separately. On the figures, (−CE) and (+CE) are rotation rates of the compact magnetic elements with negative and positive polarities, respectively; ($-CE_{av}$) and ($+CE_{av}$) are rotation rates of the compact magnetic elements of different polarities averaged over the whole cycles. The standard deviations are presented.

The arrows on the figures indicate the epochs of polarity reversal of the circumpolar regions of the Sun. Before and after the arrows, the "+" and "−" indications mark the polarity of the circumpolar regions for the given hemisphere of the Sun. Polarity reversals occurred in 1969, 1971.1, 1974.1 (the three-fold polar magnetic field reversals), and 1970.5 for cycle 20 and in 1981.0 and 1981.7 for cycle 21 in the northern and southern hemispheres, respectively (Makarov, Tlatov, and Callebaut, 1997; Makarov and Sivaraman, 1989a, 1989b).

From Figures 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, and 12 we can see that the magnetic elements having the same polarity as the polar magnetic field of the Sun have larger rotation rates than those with the opposite polarity. In all 10° zones the average rotation rates of magnetic elements with negative polarity are slightly higher than those with positive polarity, except for the 50° zone of the southern hemisphere.

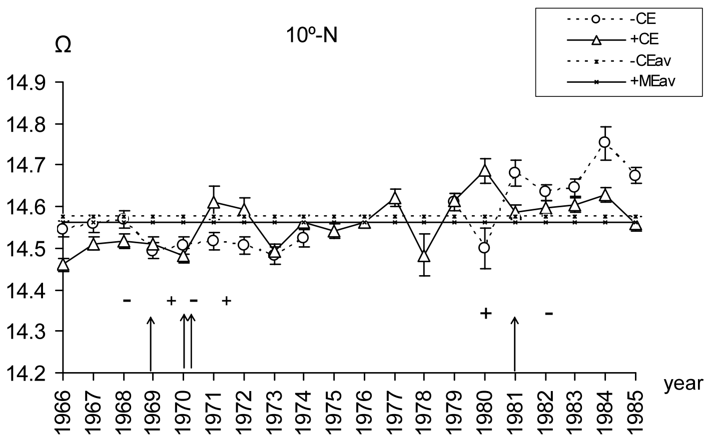

Figure 1 Rotation rate of magnetic elements with positive and negative polarities for 10° zones of the northern hemisphere. The minimum of the sunspot cycle occurred in 1976.

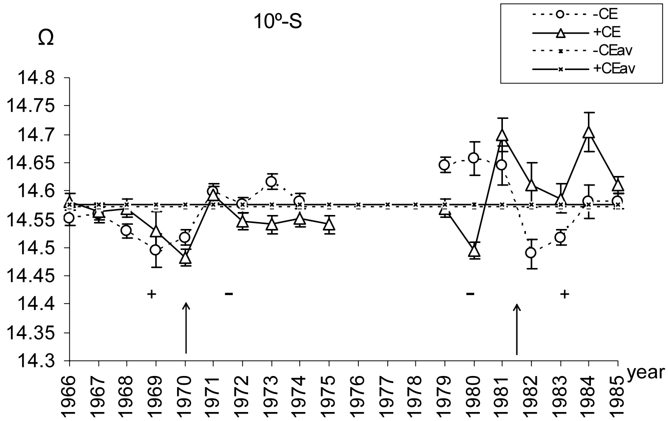

Figure 2 Rotation rate of magnetic elements with positive and negative polarities for 10° zones of the southern hemisphere.

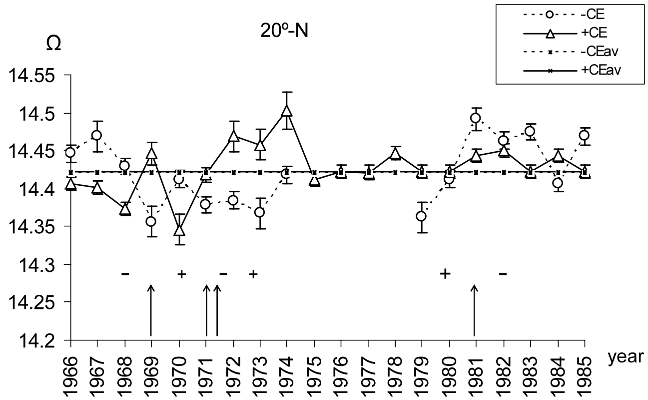

Figure 3 Rotation rate of magnetic elements with positive and negative polarities for 20° zones of the northern hemisphere.

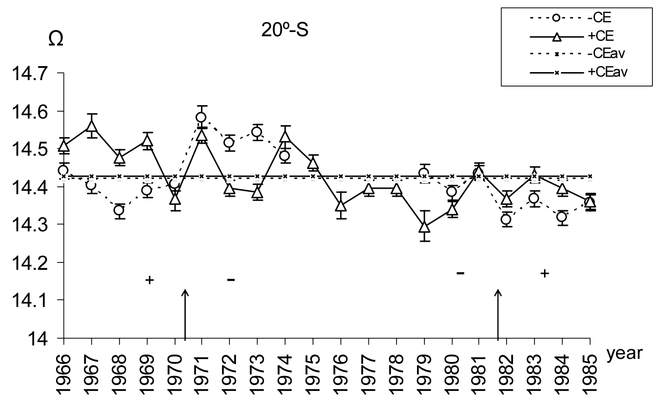

Figure 4 Rotation rate of magnetic elements with positive and negative polarity for 20° zones of the southern hemisphere.

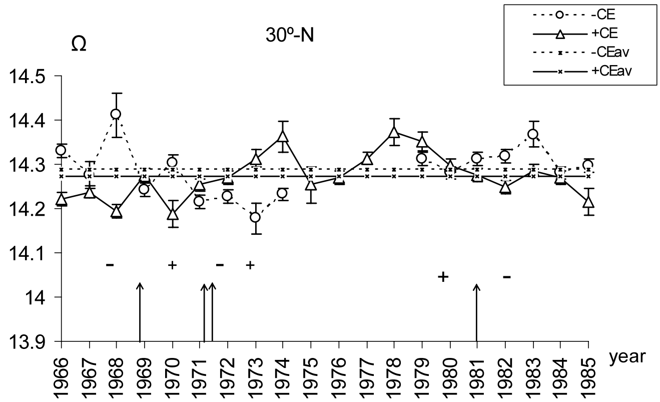

Figure 5 Rotation rate of magnetic elements with positive and negative polarities for 30° zones of the northern hemisphere.

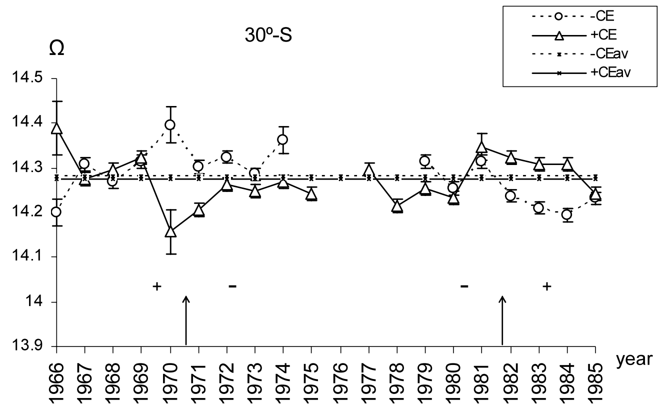

Figure 6 Rotation rate of magnetic elements with positive and negative polarity for 30° zones of the southern hemisphere.

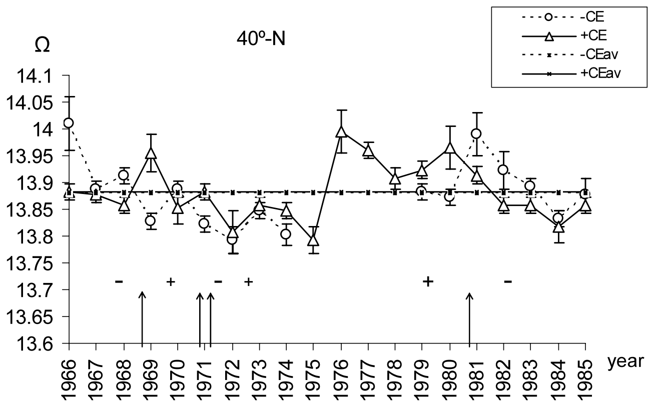

Figure 7 Rotation rate of magnetic elements with positive and negative polarities for 40° zones of the northern hemisphere.

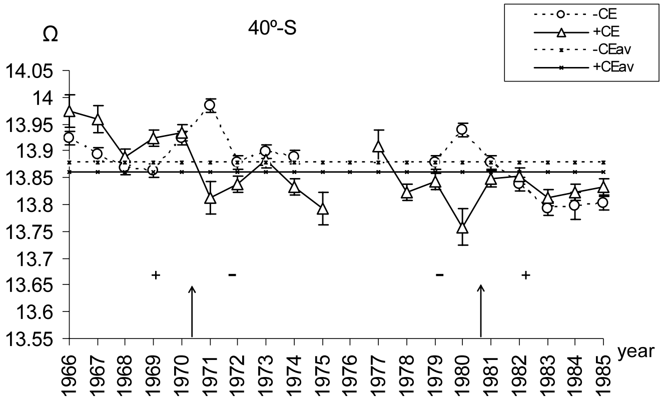

Figure 8 Rotation rate of magnetic elements with positive and negative polarity for 40° zones of the southern hemisphere.

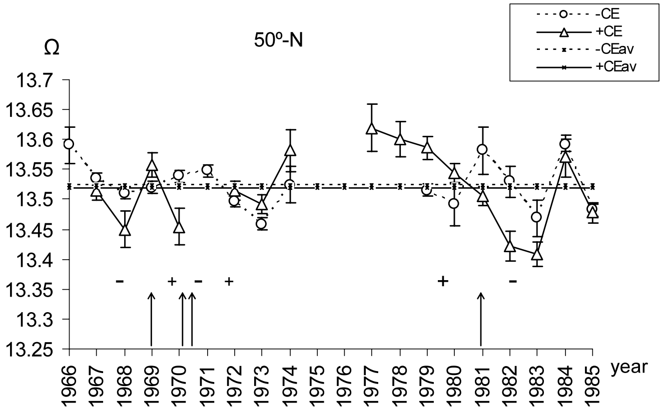

Figure 9 Rotation rate of magnetic elements with positive and negative polarities for 50° zones of the northern hemisphere.

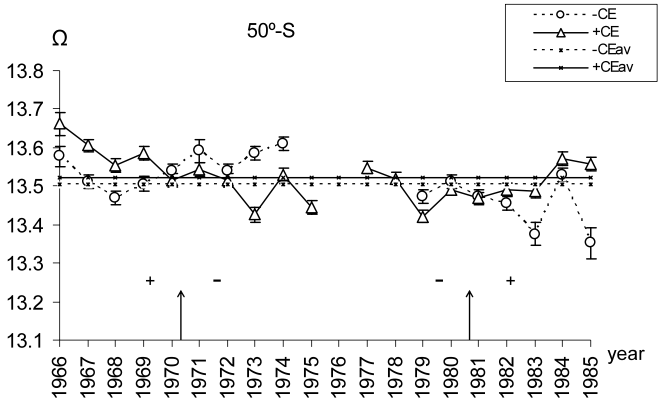

Figure 10 Rotation rate of magnetic elements with positive and negative polarity for 50° zones of the southern hemisphere.

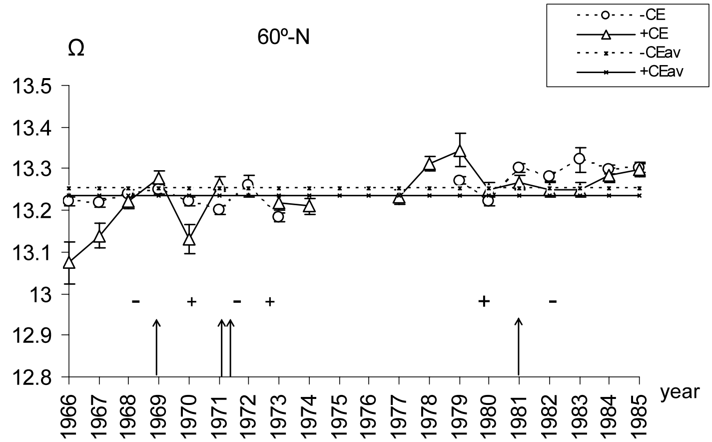

Figure 11 Rotation rate of magnetic elements with positive and negative polarities for 60° zones of the northern hemisphere.

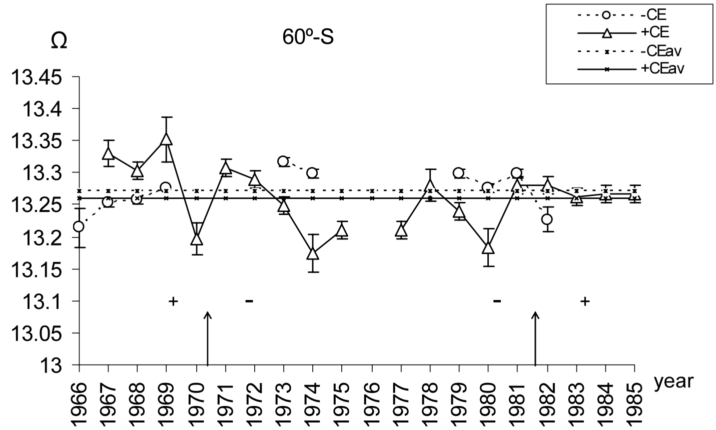

Figure 12 Rotation rate of magnetic elements with positive and negative polarity for 60° zones of the southern hemisphere.

4. Discussion

Polarity reversals of circumpolar magnetic fields happen around the time of maxima of solar cycles. During the period 1966 – 1986 the rotation rates of compact magnetic elements experienced some variations at reversal times of the circumpolar regions of the Sun. For solar cycle 20, a three-fold reversal took place in the northern hemisphere in 1969 – 1970 (Makarov, Tlatov, and Callebaut, 1997; Makarov and Sivaraman, 1989a, 1989b; Gigolashvili, Japaridze, and Kukhianidze, 2005b), where for each 10° zone of the northern hemisphere the variations of the rotation rates of magnetic elements both with positive and negative polarities can be noticed.

According to Sheeley, Nash, and Wang (1987) small-scale compact magnetic elements are parts of larger structures. They have rotation rates different from those of large-scale structures. The rates of differential rotation of the visually-symmetric compact magnetic elements with negative and positive polarities that we choose have the same behavior during the whole cycle except at the moment of polarity reversal of the circumpolar field of the Sun. At the first polarity reversal of the three-fold changing of the circumpolar magnetic field in the northern hemisphere, as well as at polarity reversal in the southern one, the rotation rates of compact magnetic elements with both polarities vary little, and all other cases showed similar variations of rates. Exceptions take place for 10° and 50° – 60° zones, where only similar variations are observed. In the southern hemisphere differences at the polarity reversal are characteristic for compact elements with both polarities for 30° – 40° intervals.

5. Conclusions

We have investigated the differential rotation of compact elements of the solar magnetic field during activity cycles 20 and 21. The differences of rates of differential rotation for compact magnetic elements with negative and positive polarities have similar behavior for both solar cycles at all stages of the cycle except for the moment of polarity reversal. For the given solar hemisphere, compact magnetic elements with polarity similar to the circumpolar magnetic field of the Sun have larger rotation rate than the elements with the opposite polarity.

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References

Brun, A.S.: 2004, *Solar Phys.* **220**, 333 – 345.
D'Azambuja, M., D'Azambuja, L.: 1948, *Ann. Obs. Paris* **6**, 1 – 278.
DeRosa, M.L., 2005, In: Sankarasubramanian, K., Penn, M., Pevtsov, A. (eds.) *Conference Large-scale Structures and Their Role in Solar Activity* **346**, Astron. Soc. Pac., San Francisco, 337 – 352.
Durrant, C.J., Turner, J., Wilson, P.R.: 2002, *Solar Phys.* **211**, 103 – 124.
Gigolashvili, M.Sh., Japaridze, D.R., Kukhianidze, V.J.: 2005a, *Solar Phys.* **231**, 23 – 28.
Gigolashvili, M., Japaridze, D., Kukhianidze, V.: 2005b, *Sci. Bord.* **2**, 136 – 144.
Gigolashvili, M.S., Japaridze, D.R., Mdzinarishvili, T.G., Chargeishvili, B.B., Kukhianidze, V.J.: 2007, *Adv. Space Res.* **40**(7), 976 – 980.
Gigolashvili, M.Sh., Japaridze, D.R., Pataraya, A.D., Zaqarashvili, T.V.: 1995, *Solar Phys.* **156**, 221 – 228.
Japaridze, D.R., Gigolashvili, M.S.: 1992, *Solar Phys.* **141**, 267 – 274.
Japaridze, D., Gigolashvili, M., Kukhianidze, V.: 2006, *Sun Geosph.* **1**(1), 31 – 34.
Japaridze, D.R., Gigolashvili, M.S., Kukhianidze, V.J.: 2007, *Adv. Space Res.* **40**(7), 1912 – 1918.
Makarov, V.I., Sivaraman, K.R.: 1989a, *Solar Phys.* **123**, 367 – 380.
Makarov, V.I., Sivaraman, K.R.: 1989b, *Solar Phys.* **119**, 35 – 44.
Makarov, V.I., Tlatov, A.G., Callebaut, D.K.: 1997, *Solar Phys.* **170**, 373 – 388.
McIntosh, P.S., Willock, E.C., Thompson, R.J.: 1991, *Atlas of Stackplots*, National Geophysical Data Center, 175 – 188.
Newbegin, A.M., Newton, H.W.: 1931, *The Observer* **54**, 20 – 21.
Newton, H.W.: 1924, *Mon. Not. Roy. Astron. Soc.* **84**, 431.
Sheeley, N.R., Nash, A.G., Wang, Y.M.: 1987, *Astrophys. J.* **319**, 481 – 502.
Snodgrass, H.B.: 1992, In: Harvey, K.L. (ed.) *Conference The Solar Cycle* **CS-27**, Astron. Soc. Pac., San Francisco, 205 – 240.
Snodgrass, H.B., Smith, A.A.: 2001, *Astrophys. J.* **546**, 528 – 541.